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Irrigation for vegetable crops in Iowa

A. T. Erwin
Iowa State College

E. S. Haber
Iowa State College

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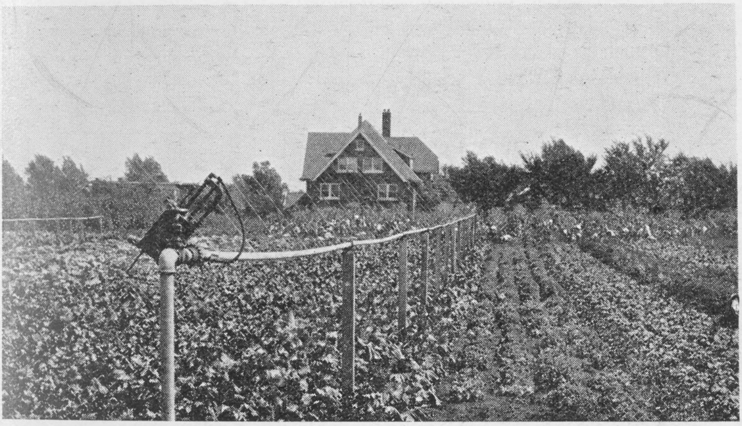
Irrigation for Vegetable Crops in Iowa

By A. T. ERWIN and E. S. HABER



Overhead irrigation line with automatic turning device, operating by pressure of the water.

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE AND MECHANIC ARTS

R. E. BUCHANAN, Director

HORTICULTURE AND FORESTRY SECTION

VEGETABLE CROPS SUBSECTION

AMES, IOWA

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SUMMARY

TWO types of irrigation were tested, the overhead irrigation system (at Ames) and the furrow system (tested on the "Muscatine Island").

With the overhead system the results with the different crops were as follows:

1. Snap beans—no advantages from irrigation resulted. The variety, Bountiful, was used. One planting was made in 1928 and two in 1929.

2. Lima beans—the plot not irrigated yielded more than the irrigated. One planting was made in 1928 and two in 1929 with the variety, Burpee's Improved Lima.

3. Beets—large increases in yields resulted, and the irrigated beets were decidedly superior in tenderness and quality. The tests were made over a 6-year period with two plantings per season of Crosby. Two plantings of Detroit Dark Red were made in 1927.

4. Carrots—in 3 of 5 years, irrigation resulted in marked gains with the Chantenay variety. In the other 2 years (1928 and 1929) the yields of irrigated and unirrigated plots were practically the same. Danvers Half Long variety showed gains of 55 and 195 percent in 1928 and 1930, with no gain from irrigation in 1929. Coreless showed gains of 143 and 102 percent in 1926 and 1927. The quality of carrots was greatly improved by irrigation.

5. Onions from seed—over a 5-year period irrigation showed an average gain in yield of 69.6 percent with the variety, Southport Yellow Globe, and 89.1 percent with Riverside Sweet Spanish.

6. Onions from transplants—the irrigated plot produced 209.5 percent more than the check plot in 1926, 71 percent more in 1927, no difference in 1928 and 1929, and in 1930 the check plot outyielded the irrigated plot. Irrigated onions were milder in flavor and the color was appreciably better than that of the unirrigated.

7. Parsnips—irrigation increased the yield in 3 of 6 years, but this vegetable sells at so low a price that irrigation usually will not pay.

8. Radishes—irrigation increased the yield and improved the quality in each of the 6 years.

9. Tomatoes—in 4 of the 5 years, irrigation improved the yield. The average gain was 67.4 percent.

With furrow irrigation on the Muscatine Island, the results were:

1. Muskmelons—the irrigated plots outyielded the check plots in each of the 4 years, the increases ranging from 9.9 percent to 106 percent. The tests were made in 1925, 1926, 1928 and 1930.

2. Sweet potatoes—irrigated plots averaged for the 6 years of the experiments 134.8 bushels per acre as compared with 99.6 for the check. The percentage of marketable crop was greatly increased by irrigation. In 4 of the 6 years the differences in yield were significant, and in 1931 irrigation meant the difference between a crop and complete failure.

A straw mulch 6 inches deep greatly increased the yield of tomatoes in 4 years out of 5 in tests with overhead irrigation at Ames. Paper mulch did not prove practical in tests either at Ames with overhead irrigation or on the "Muscatine Island" with furrow irrigation.

Irrigation for Vegetable Crops in Iowa*

By A. T. ERWIN and E. S. HABER**

Does it pay to irrigate vegetable crops in Iowa?

What does it cost to irrigate? and under what conditions are these costs, plus a profit, returned to the vegetable grower?

No complete answer to these questions can be given, because of the widely varying conditions involved—differences of rainfall, of crops, of costs, of soil, of topography. But considerable light is thrown on them by experiments which the Vegetable Crops Subsection of the Iowa Agricultural Experiment Station has conducted during several years at Ames and on "Muscatine Island."

It is the purpose of this publication to give the results of these experiments—one of which used the overhead sprinkler system and the other the furrow system of irrigation. The data from these experiments should furnish a basis upon which vegetable growers in other sections can estimate the probable costs of irrigation and the probable benefits.

Several factors have a direct bearing on the problem of irrigation—rainfall, temperature, sources of water supply, quantity of water needed for irrigation, the relation of irrigation to cultural methods and when to irrigate—which need to be considered before we take up the results of our experiments.

RAINFALL

Because, in general, the normal annual precipitation in Iowa is ample for the production of vegetable crops, irrigation must be regarded as **crop insurance.** The question is, then, how frequently do drouths injurious to vegetable crops occur in Iowa? and how much can crops be increased in such periods by irrigation?

The critical months for vegetable production in Iowa, from the standpoint of moisture supply, are June, July and August.

A study of the records of the Des Moines station of the United States Weather Bureau shows that summer drouths occur on an average of one year in three, that their average duration is 26 days, that the range in duration is between 15 and 45 days and that the average rainfall deficiency during drouths is 2.87 inches.

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*Project 5 (old series) of the Iowa Agricultural Experiment Station.

**The authors express appreciation to Mr. Charles D. Reed, senior meteorologist, U. S. Weather Bureau, for access to the records of his office and also for helpful suggestions. The assistance of Mr. L. B. Hoopes and Mr. N. D. Morgan, who cooperated with the work in the field plots at Muscatine, is also acknowledged.

The moisture supply in the subsoil at the beginning of a drouth has, of course, an important bearing on the effect of the drouth.

It is generally accepted that ¼ inch of water, either from irrigation or rainfall, is a minimum application for vegetable production. In most instances, however, a minimum application is not the most profitable one. In dry seasons, at least double this amount can be applied to advantage.

The number of decades[1] during the summer months having less than ¼ inch of rainfall is suggestive of the possible need for supplementary irrigation of vegetables. Four such periods occurred in each of the years 1926, 1927, 1930 and 1931, and one in 1929.

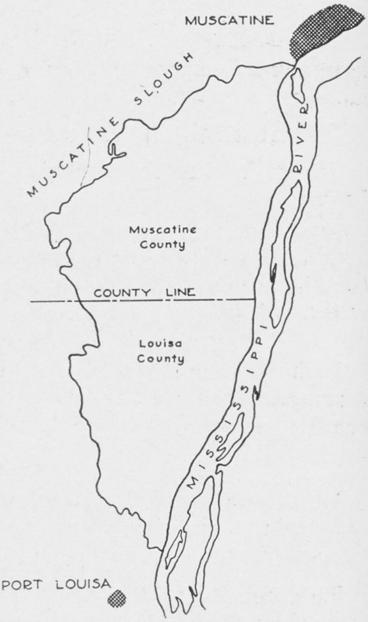

Fig. 1. The above area known as "Muscatine Island" lies between the Mississippi River and the Muscatine slough and comprises approximately 25 thousand acres.

TEMPERATURE

High temperatures (90° F. or above) usually accompany summer drouths. Such temperatures do two things: they deplete the supply of soil moisture, and they increase the water requirements of the plant.

For these reasons, even in seasons of normal rainfall, irrigation may be an important factor in tiding over temporary periods of high temperature. That such conditions are not infrequent is shown by table 1.

TABLE 1. NUMBER OF DAYS WITH TEMPERATURES ABOVE 90°F. FOR MONTHS AND YEARS INDICATED.

	1925	1926	1927	1928	1929	1930	1931
June	7	4	4	3	3	4	13
July	12	7	11	9	6	22	18
August	4	5	2	12	3	16	6
Total	23	16	17	24	12	42	37

[1] In climatological data the decade, or 10-day period, is the standard unit.

Temperatures of 90°F. or even higher are not necessarily detrimental except as they are accompanied by a deficiency in moisture supply.

SOURCES OF WATER SUPPLY FOR IRRIGATION

The following are the chief sources of water for irrigation in Iowa:

Streams

Only in rare instances is the fall of a stream in Iowa sufficient for the water to be taken out of the stream through a lateral without a lift.

Pumping

In flood plains and river bottoms water can be pumped with a comparatively short lift. For this reason such areas are most readily irrigated on a commercial scale.

Reservoirs

In upland areas the problem of water supply is difficult and may involve the impounding of water in reservoirs.

Artesian Wells

This supply is limited to the upland artesian basins, which are chiefly located in the northern half of the state.

Municipal Water Supply

As a rule water from this source must be used sparingly because of the cost. Its use is, therefore, confined to overhead irrigation. The cost of city water ranges from 10 to 20 cents per thousand gallons.

QUANTITY OF WATER REQUIRED

The amount of water necessary to maintain the best conditions for plant growth and the length of the periods between applications, either in the form of rain or irrigation, vary with the crop, the type of soil and climatic factors, particularly temperature and wind.

The size of the plants and the amount of their foliage influence the amount of irrigation water that is desirable. Shallow-rooted crops, such as radishes and onions, require, as a rule, more frequent applications of water than tomatoes or carrots.

Light and frequent watering is inadvisable. According to studies made by Williams[2] for humid regions, an application of not more than ¼ inch is considered sufficient for seedbeds and young vegetables and from ½ to 1 inch for maturing garden crops.

One inch of water over an acre of land, known as an acre-inch, requires 27,152 gallons or approximately 110 tons.

IRRIGATION IN RELATION TO CULTURAL PRACTICES

Irrigation may serve as an aid to cultural practices in a number of ways:

1. To tide over periods of drouth which might otherwise wipe out or materially reduce the yield.
2. To make it posible, through the control of moisture conditions to produce larger yields.
3. To insure a better quality of vegetables by making possible continuous growth, which is necessary to high quality.
4. To obtain a good start for vegetables transplanted into a dry soil.
5. To obtain prompt germination at sowing time. This is especially important in the case of succession of crops, which, if delayed, may miss the higher markets or be damaged by frost.
6. To make possible the preparation of ground which, without irrigation, would be too dry for plowing or pulverizing.
7. To protect certain crops from light frost injury (overhead irrigation).

The foregoing points represent the advantages of irrigation. This does not mean, however, that irrigation will necessarily pay. Against these advantages must be set the cost of irrigation, before a fair judgment of the economic value of irrigation can be reached.

WHEN TO IRRIGATE

There are no hard and fast rules by which to answer this question. The best guide is the plant itself.

The checking of plant growth is a sign that moisture is needed.

Wilting is another sign. Temporary wilting, such as affects plants on hot days, is not necessarily a symptom of moisture deficiency. Plants will recover from such wilting if there is sufficient water in the soil. But if they remain flaccid until early morning, we have indications of permanent wilting, and water should be applied promptly. If the wilting is allowed to continue, the quality and succulence of the crop are likely to be seriously impaired and the yield greatly reduced.

An examination of the soil is also helpful in determining moisture conditions. The plant itself is, however, the best indicator.

The question is frequently asked: Is it injurious to irrigate when the sun is shining? There need be no hesitation in watering plants at any time they need it. In the case of overhead irrigation less water is lost from evaporation at night because of the lower temperature and higher humidity.

[2] Williams, Milo B. Spray irrigation. U. S. Dept. Agr., Bul. 495. 1917.

PLAN OF EXPERIMENT

Two types of irrigation were involved in this study: the overhead sprinkler system, used at Ames, and the furrow system, used on "Muscatine Island."

With the exception of tomatoes, four one-row replicates, each row 100 feet long, of each variety were harvested. The yields given in this publication represent an average of the four replicates. The variety used and the cultural conditions were identical in the check and irrigated plots of each series.

The porous hose system developed by Robey[3] has been introduced since this experiment was consummated. A preliminary trial of this method in 1933 on tomatoes indicates that this system can be used to advantage under certain conditions, particularly where the cost of water is an important item.

AMES PLOTS—SPRINKLER SYSTEM

Equipment

The initial outlay for equipment for an overhead system for one acre, exclusive of pump and power, was estimated at $400 (1929 price). Interest on the investment at 6 percent would be $24 per acre yearly and the annual charge-off for depreciation (20-year preiod) at 5 percent would be $20. The item of repairs is practically nil. Aside from an occasional adjustment of the water motors which turn the sprinkler lines, there were no repairs during the period of the experiment. The cost of water per acre inch was arbitrarily placed at 10 cents per thousand gallons or $2.72 per acre inch. By readjusting the above figures to fit his local conditions, a grower may determine his irrigation costs for a given season.

In the tables which follow, the amount of water used on the irrigated plots and the cost of this water are given.

Snap Beans

The variety Bountiful was used. One planting was made in 1928 and two in 1929.

TABLE 2. YIELD OF SNAP BEANS—BOUNTIFUL.

	1928		1929 First planting		1929 Second planting	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight — pounds	33	33	32	32	42	43
Percentage increase	0		0		—2.38	

An average of 4.7 acre inches per crop was applied at a cost for the water of $12.74 per acre, plus overhead costs.

[3] Robey, D. E. Irrigating potatoes with a porous hose. Mich. Agr. Exp. Sta., Quarterly Bul. Vol. XIV, No. 5. 1932.

No advantages were secured from the irrigation of snap beans. The irrigated plots averaged, for the three plantings, 35.6 pounds and the check plots averaged 36 pounds.

Lima Beans

In 1928 one planting of Burpee's Improved Lima was made and in 1929 two plantings.

TABLE 3. YIELD OF LIMA BEANS—FORDHOOK AND BURPEE'S IMPORVED.

	1928		1929 First planting		1929 Second planting	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight — pounds	38	38	38.5	38.7	38.2	38.5
Percentage increase	0		—0.52		—0.78	

An average of 5.6 acre inches per crop was applied at a cost for the water of $15.18 per acre, plus overhead costs.

The check plots produced slightly larger yields than the irrigated ones.

Lloyd[4] reports a gain of 24 percent from the irrigation of lima beans. Lima beans are a heat-loving plant. They are usually grown commercially on warm, sandy soils. On such soils irrigation may prove more beneficial than on the heavy loam found at Ames. The returns per acre are not so high for beans as for a number of other vegetable crops. The increase from irrigation must, therefore, be large to justify the added expense. Summers with serious moisture deficiencies are usually marked by high temperatures, which increase the percentage of blossom drop with the result that only moderate yields are obtained even though an ample supply of water is applied.

Beets

Crosby was used for first and second plantings during 6 years. In addition two plantings of Detroit Dark Red were made in 1927. The first crop was, in most instances, planted during the last of April and matured in from 60 to 70 days. The second plantings were usually made in the second or third week of June.

The irrigation of beets resulted in large increases in yield and, further, the irrigated crops were decidedly superior in tenderness and quality.

Marked gains were obtained from irrigation during the first 3 years of the experiment, the average increase being 119.7 percent. Two plantings of Detroit Dark Red in 1927 gave an average gain of 93 percent in favor of irrigation (not included in table 4).

[4] Lloyd, J. W. Bush lima beans as a market garden crop. Ill. Agr. Exp. Sta., Bul. 307. 1928.

TABLE 4. YIELD OF BEETS—CROSBY EGYPTIAN.
AVERAGE OF FIRST AND SECOND PLANTINGS.

	1925		1926		1927	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	250	125	153	73	151	75
Salable beets weight—pounds	172	84	116	51	125	55
Percentage increase salable beets	104.7		127.4		127.1	

	1928		1929		1930	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	305	249	120	97	127	104
Salable beets weight—pounds	281	222	103	82	111	93
Percentage increase in salable beets	26.6		25.6		19.3	

An average of 3.1 acre inches of water per crop was applied to beets at a cost of $8.49 per acre for water, plus overhead costs.

In 1928 rainfall was favorable and excellent yields were obtained from both irrigated and check plots. Both 1929 and 1930 were seasons of high temperatures. The beet is a cool-season crop, and difficulty was experienced in these years in obtaining a stand because the plants sun-scalded at the germination stage. In the case of certain vegetables, of which the beet is one, there are conditions under which temperature as well as moisture is a limiting factor.

Carrots

The Chantenay, probably the leading variety in the Corn Belt, was grown for 5 years of the experiment. Plantings were also made of the Danvers Half Long in 1928, 1929 and 1930 and the Coreless in 1926 and 1927. First plantings were usually made the last week in April. The Chantenay reached marketable size in from 70 to 80 days. The other two varieties required an additional week to 10 days.

The results with the Chantenay, given in table 5, indicate a wide variation in the need of this plant for supplementary water. In 3 of the 5 years, irrigation resulted in marked gains, the average for the 3 years being 112 percent. On the other hand, there was little or no gain in 1928 and 1929.

The results with the Danvers Half Long were as follows: In 1928 the average for the two plantings showed a gain of 55 percent in favor of irrigation; in 1929 the yields were practically the same; in 1930, a year of low rainfall and high temperatures, the irrigated plots showed a gain of 195 percent over the check.

The Coreless, grown in 1926 and 1927, produced in the former year 143 percent more carrots on the irrigated plots than on the checks, and in the latter year 102 percent more.

Yields, however, tell but half the story in the case of the carrot. An increasing percentage of the crop is being consumed raw. For such use a tender product is the first consideration. The absence of tough fibrous material in the irrigated roots, as compared with the unirrigated, was marked—and had a direct bearing on the salability of the product.

TABLE 5. YIELD OF CARROTS—CHANTENAY. AVERAGE OF FIRST AND SECOND PLANTINGS.

	1926		1927		1928	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	180	108	131	54	109	109
Salable carrots weight—pounds	157	102	128	47	99	100
Percentage increase in salable carrots	54.0		172.0		—1.0	

	1929		1930	
	Irrig.	Check	Irrig.	Check
Total weight—pounds	82	72	94	54
Salable carrots weight—pounds	80	70	91	43
Percentage increase in salable carrots	14.3		111.5	

The average application of water per crop of carrots was 7 acre inches for the first planting and 4 acre inches for the second or a water cost of $18.97 and $10.84 per acre, respectively.

In general the best results from the irrigation of carrots were obtained with the first plantings. In 1930, for example, four successive attempts were made to get a stand of the second planting and they all failed. On the check plots, the seed failed to germinate. On the irrigated plots, the seed sprouted, but the plants were killed by the intense heat.

Onions—from Seed

Southport Yellow Globe and Riverside Sweet Spanish were planted, usually in the last week in April. The crops matured in about 125 days.

The average yield for the Southport Yellow Globe for the 5 years was as follows: Irrigated, 56 pounds per plot; check, 33 pounds per plot; a difference of 69.6 percent in favor of irrigation.

The average yield for the Riverside Sweet Spanish for the

TABLE 6. YIELD OF ONIONS—SOUTHPORT YELLOW GLOBE.

	1926		1927		1928	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	80	21	32	21	75	76
Salable onions weight—pounds	80	21	30	21	66	66
Percentage increase in salable onions	281.0		42.9		0	

	1929		1930	
	Irrig.	Check	Irrig.	Check
Total weight—pounds	30	29	66	19
Salable onions weight—pounds	22	21	35	0
Percentage increase in salable onions	4.76			

5 years was: Irrigated, 139 pounds per plot; check, 73.5 pounds per plot; a difference of 89.1 percent.

Onions—Transplants

Transplants of the Bermuda variety were set out in the last week in April.

The results of irrigation varied widely in the 5 years of the experiment. In 1930 the irrigated plots produced a slightly smaller crop of salable onions than the check plot, while in 1926 the increase of salable onions on the irrigated plot was 209.5 percent.

TABLE 7. YIELD OF ONIONS—RIVERSIDE SWEET SPANISH.

	1926		1927		1928	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	176	74	179	54	161	118
Salable onions weight—pounds*	176	74	179	54	130	101
Percentage increase in salable onions	138.0		231.5		28.7	

	1929		1930	
	Irrig.	Check	Irrig.	Check
Total weight—pounds	108	102	72	17
Salable onions weight—pounds*	96	94	66	3
Percentage increase in salable onions	2.13		2100.0	

*U. S. Grade No. 1 used.

An average application of 8.2 acre inches per crop was applied to onions at a cost for water of $22.22 per acre, plus overhead costs.

TABLE 8. YIELD OF ONIONS—BERMUDA TRANSPLANTS.

	1926		1927		1928	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	100	32	67	40	77	68
Salable onions weight—pounds*	99	32	65	38	65	65
Percentage increase in salable onions	209.5		71.0		0	

	1929		1930	
	Irrig.	Check	Irrig.	Check
Total weight—pounds	63	64	28	27
Salable onions weight—pounds*	63	63	25	26
Percentage increase in salable onions	0		—3.85	

*Based on U. S. Grade No. 1.

A striking difference in pungency was observed between the onions from the irrigated plots and the check plots. A rapid, continuous growth insures a relatively mild flavor in onions, and, conversely, even with the so-caled ''sweet'' onions, a check in the growth results in a ''hot,'' pungent flavor.

Bulbs from irrigated plots showed an appreciably better color than those from the check plots.

Caution should be exercised in applying water to onions. A moist soil and uniform supply of water are essential during the ''filling out'' stage of the bulb. Dry soil is equally essential for the curing of the bulb. Irrigation applied after the bulbs have begun to ripen is likely to result in a water-soaked bulb of poor keeping quality.

Parsnips

In 3 out of 6 years, yields of Hollow Crown parsnips were increased by irrigation. In 1930, an extremely dry year, the increase was 420 percent.

Parsnips are a slow-maturing, cool-season crop, and require a full season for maturity, and sell at a comparatively low price. It is probable that such increase in yields as is secured from irrigation can also be secured from the fall rains hence, irrigation usually will not pay with this crop.

Radishes

Early Scarlet Globe was the variety used. The first plantings were commonly made during the last week in March. The

TABLE 9. YIELD OF RADISHES—EARLY SCARLET GLOBE. AVERAGE YIELD FIRST AND SECOND CROP.

	1925		1926		1927	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	20.8	12.8	33.2	18.0	15.0	13.7
Salable radishes weight—pounds	20.7	12.0	29.1	13.7	13.0	12.2
Percentage increase in salable radishes	72.5		112.4		6.5	

	1928		1929		1930	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total weight—pounds	18.0	14.8	16.8	15.1	18.5	14.0
Salable radishes weight—pounds	15.0	13.2	15.6	12.6	5.5	2.5
Percentage increase in salable radishes	13.6		23.8		120.0	

An average application of 3.2 acre inches per crop was applied to radishes at an equivalent cost of $8.67 per acre, plus overhead costs.

crop matured in about 40 days. The irrigated plots yielded marketable radishes in 25 days.

The irrigated plots gave larger yields than the check plots in each of the 6 years of the experiment. In 3 years the increase was marked.

Beside the increase in yield, other very marked advantages were obtained from irrigation:

1. Crispness and flavor were improved by irrigation. In a warm dry soil the roots become tough and peppery. The quality of no other crop is more greatly influenced by irrigation than radishes.

2. Comparative freedom from radish scab characterized the irrigated plants. In 1926 the check plots produced 80 percent of radishes that were unsalable because of scab, as against 10 percent from the irrigated plots. The scab organism was identified by the Station Pathologist, Dr. I. E. Melhus, as *Actinomyces scabies.*

3. The irrigated radishes were distinctly larger than the unirrigated. Measurements made in 1926, for example, showed that the roots from the check plots averaged 7.8 cm. in length and the irrigated 8.7 cm., a difference of 11.5 percent.

Because radishes are a cool-season crop and the first planting is therefore made rather early, irrigation will usually prove more valuable for the second planting than for the first.

Tomatoes

The variety, Perfection, was used for the 6 years of the experiment. The plants were grown in the college greenhouse and shifted from 4-inch pots to the field after danger of frost was past, which was usually about the third week in May, the exact date varying from year to year. Thirty-six plants were included in each plot, and each plot was duplicated.

TABLE 10. YIELD OF TOMATOES IN POUNDS PER PLANT.

	1925	1926	1927	1928	1929	1930
Check	13.1	17.5	13.6	25.7	33.5	21.8
Irrigated	19.4	26.5	20.2	25.5	......	44.4
Percentage increase	48.0	51.5	48.5	—0.8	......	103.7

The amount of water applied per crop per year for tomatoes shows a wider range than with other crops and averages are not figured. In 1928, for example, 1.5 acre inches were applied as compared with 22 acre inches for the dry year of 1930.

The irrigated plots gave important increases in yield during the first 3 years and the last year of the experiment. In these 4 years the average gain was 67.4 percent. In 1928 the irrigated and check plots yielded approximately the same amount. In 1929, because the precipitation was adequate for tomatoes, the crop was not irrigated.

High temperatures usually accompany moisture deficiency. While irrigation will correct the latter difficulty, it will not compensate for the former.

When temperatures are excessive, tomatoes are frequently affected with "blossom drop," which is thought to be caused by heat damage to the pollen. "Blossom drop" limits the setting of the fruit and the ultimate yield, irrespective of the water supply.

The amount of water applied per crop per year for tomatoes shows a wider range than with other crops and averages are not figured. In 1928, for example, 1.5 acre inches were applied as compared with 22 acre inches for the dry year of 1930.

Blossom end rot is a non-parasitic disease of tomatoes. This malady is associated with extreme fluctuations in the moisture supply and is characterized by the appearance of small "water soaked spots" on the blossom end of the fruit. These spots become leathery and enlarge as the fruit develops, rendering it unmarketable. This investigation did not relate to a study of blossom end rot, but it was noted that the increase in percentage of unmarketable fruits from the check plots, due to this trouble, was very marked in dry seasons. In certain seasons irrigation may give good returns by the reduction of blossom end rot.

MUSCATINE PLOTS—FURROW IRRIGATION

Southeastern Iowa is the most important trucking area in the state. The area known as "Muscatine Island," in Muscatine and Louisa counties, Iowa, lies just south of the city of Muscatine. It is bounded by the Mississippi River on the east and the Muscatine slough, a former river channel, on the west. The island, roughly semi-elliptical in shape, has a maximum width of about 5 miles, a maximum length of about 11 miles and comprises approximately 25,000 acres with an average elevation of 545 feet. The major portion of the land lies in Muscatine County, with the remaining portion in the north end of Louisa County. (See fig. 1 on page 118.)

Rainfall

The normal rainfall, computed from 60 years' records at the Davenport station, the official station nearest to "Muscatine Island," is 32.56 inches a year. In 26 of the 60 years there was less than normal rainfall.[5]

Temperature

In two of the years during which the experiment was conducted—1930 and 1931—the temperatures at the Davenport station were high. In 1930 there were 28 days with maximum temperatures above 90° F; and in 1931 there were 34 such days. Eleven days in the latter part of June had temperatures above 100° F.

Soil Type

The soil in most of the Muscatine County portion of the "Island" is classified in the Buckner series.[6] The soil involved in the trial reported here is in Buckner sands.

The top soil in this area extends to a depth of 18 to 20 inches and is a brown or dark brown or black loamy sand, medium in texture and loose, porous and friable in structure. In topography, the type is generally flat to very slightly rolling. Drainage is good to excessive. Incorporation of organic matter in the soil would reduce the danger from drouth injury to crops.

The water table lies from 8 to 10 feet below the surface. Measurements taken in June were 8½ feet, and at no time during the summer was the depth greater than 10 feet. These figures were secured at Fruitland where the irrigation tests were made.

The Mississippi River is regarded locally as the source of supply of ground water of the "Muscatine Island." In 1928,

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[5] See Appendix for a more detailed discussion of rainfall.

[6] For further details consult Soil Survey of Iowa, Report No. 3, Muscatine County, Iowa Agr. Exp. Sta.

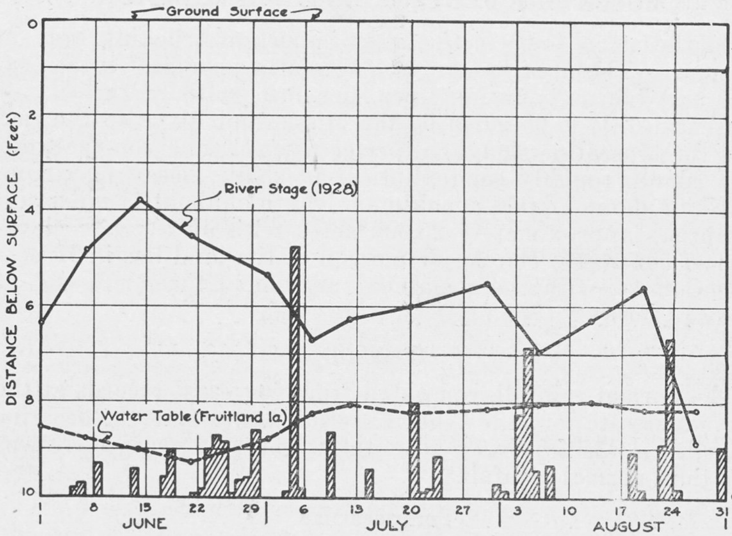

Fig. 2. Graph showing the height of the water table and the Mississippi River stage for the summer months of 1928 at Muscatine. The summer rainfall is indicated by the length of bars.

water table readings were taken at weekly intervals for the summer season. The graph in fig. 2 gives this record and also the precipitation and Mississippi stages for the summer of 1928. A study of this suggests that the level of the ground water is more directly influenced by summer rains than by river stages.

The water-holding capacity of these sandy soils is lower than that of the loams. Determinations made by B. J. Firkins, of the Soils Subsection, showed that the Buckner sand had a water-holding capacity of approximately 19 percent. This is the equivalent of 1.93 gallons per cubic foot or 84,070 gallons per acre to the depth of one foot. Similar readings taken on the Carrington loam of the experimental plots at Ames showed a water-holding capacity of 36 percent—equivalent to 3.67 gallons per cubic foot or 159,865 gallons per acre-foot.

Equipment

The wells used on the station plots were driven and consisted of a 6-inch casing 38 feet in length, the lower 12 feet of which were perforated and constituted the "sand point." In the point were drilled 7/16 inch holes, 125 to the foot. After the well was driven, 3 or 4 cubic yards of coarse pebbles were dumped around the top of the casing. The sand was then pumped from around the sand point and as it was removed the surface at the top of the well gradually caved in. This process was continued until the pebbles finally reached the bottom of the well. This placed a zone of coarse material around the sand point and thus facilitated the free movement of water.

The centrifugal pump used in the experiment is equipped with a 6-inch intake and 5-inch discharge and has a capacity of 500 gallons per minute. Such a pump has many advantages because of its simplicity of design, few wearing parts and the fact that it is not affected by abrasive action of the sand. The power is furnished by a 5-horsepower portable electric motor.

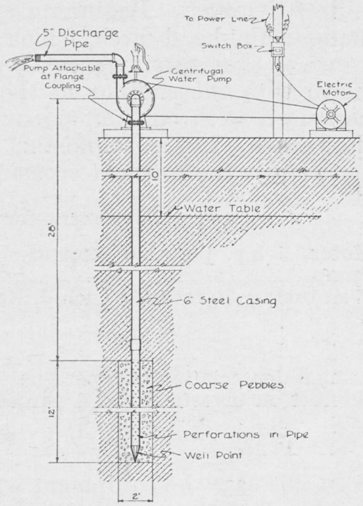

Fig. 3. A diagram of the centrifugal pump used on "Muscatine Island." It shows the casing and "sand point" in position.

Furrow Irrigation

The furrow system is very generally used on the island. A well is provided for each 7 to 10 acres. It is usually located

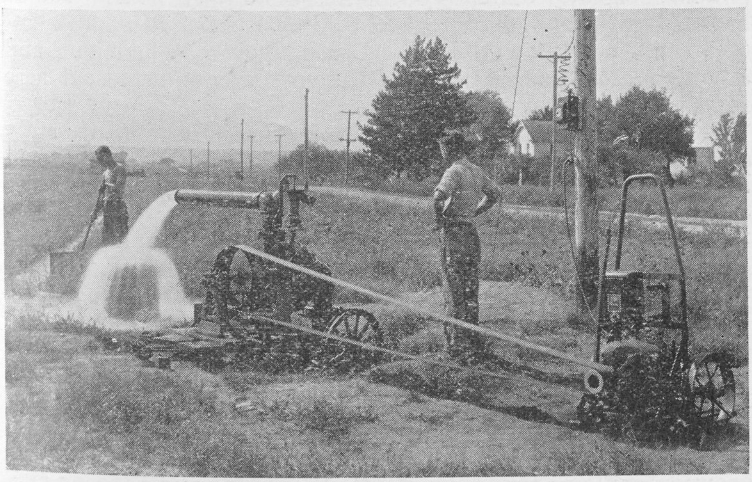

Fig. 4. The equipment for furrow irrigation consists of a 5-horsepower electric motor and centrifugal pump; the motor and pump are both portable.

on the highest point of the land it is to serve. By means of a head ditch the water is conducted from the pump to the farther end of the tract. Beginning at the farthest end, openings are made in the head ditch, which admit the water to the furrows between the rows. In many instances the head ditch must curve with the contour of the land. Some difficulty was experienced with cutting, particularly on the outside banks of the curves. It was found that long strips of burlap, so placed as to cover the zones of erosion, corrected this difficulty.

Equipment for Furrow System

Motor, 5 h.p. portable electric	$200.00
Pump	150.00
Well tubing, 30 feet of 6-inch drilled	75.00
	$425.00
Annual depreciation at 5 percent	$ 21.25
Interest on investment at 6 percent	25.50
	$ 46.75

In this case the equipment was used on a 10-acre tract which would involve an overhead charge of $4.67 an acre. The fact should be noted, however, that the motor and pump were probably idle half the time. In other words, this equipment could handle double the acreage named, which would, in turn, reduce the overhead costs correspondingly.

The pump used on the experimental plots has a capacity of 500 gallons per minute. This provides an application of 30,000 gallons, or approximately an acre-inch, per hour. The 5-horsepower electric motor, used 4 kilowatts per hour, at a cost of 5 cents per kilowatt hour. Based upon a 10-hour run and a coverage of 3 acres per day, the cost was 66 cents per acre for each irrigation for current.

Seepage is an important factor in the irrigation of sandy soils. The lay of the land and the distance the water has to be carried from the pump are other factors that influence the efficiency of operation.

In practice it was found that the pump would apply an inch of water to about 3 acres a day, instead of 7 or 8 acres, the theoretical coverage. The difference represents seepage loss. Possible ways of cutting down this loss are the installation of more wells per unit area and the use of an inexpensive liner for the main ditches.

An effort was made to secure cost data from a number of growers. The gasoline engines used ranged from 6 to 12 horsepower. Many of them were operated at low efficiency. Some growers employ a tender to operate the engine and a second man to handle the water. Some growers turn the vines back onto the rows to facilitate the flow of water; others prefer that the vines be left in the furrows to retard the flow. On the station plots a sheet metal gate was used at intervals to hold the water until it flooded over the ridges, to insure soakage. Many of the growers estimated that they averaged from 2 to 3 acres in a 10-hour day.

Results With Crops

Muskmelons

The muskmelon is highly sensitive to moisture deficiency. It has a root system "consisting of a very extensive shallow portion and a poorly developed deeper part."[8]

The experimental plots were planted usually the third week in May and the harvesting was completed by the third week in August. Defender was the variety used.

TABLE 11. YIELD OF MUSKMELONS*
(Number of melons per plot)

	1925	1926	1928	1930	Average
Irrigated	330	400	370	300	350
Check	160	364	290	....	203
Percentage increase	106.0	9.9	27.6	....	72.4

*No records were obtained in 1927 and 1929.

Yield records were taken on the basis of numerical count rather than weight of melons because melons are marketed in this way. The records for the 4 years show a striking uniformity of yield from the irrigated plots as compared with a wide range of yields from the check plots. The increase in yield of the irrigated plots over the check plots ranged from 9.9 percent in 1926 to 106 percent in 1925.

In 1930 the check plot was a total failure. Rainfall for August of that year was 58 percent below normal. Abnormally high temperatures also prevailed during the summer of 1930. During the latter half of July and the first week of August, temperatures of 100 degrees to 105 degrees F. were not infrequent.

In the early stages of the development of the muskmelon, an ample and evenly distributed supply of moisture is necessary. On the other hand, an oversupply of moisture either from irrigation or rain when the melons are reaching maturity may prove a serious detriment from the standpoint of over-sized and cracked melons.

The following record is given as an example of this point. A field of the variety, Defender, grown under the supervision of the senior author on the farm of Mr. Elmer Corwin was irri-

[8] Weaver, John E., and Bruner, William E. Root development of vegetable crops. p. 290. McGraw-Hill Book Co., New York. 1927.

gated three times in July and once in the first week in August. At the time of the last watering the irrigated plots showed a marked superiority in the vigor of the plants and in their maturity. On Aug. 7, 1928, the day following the last irrigation, there was a rainfall of 1 inch. Four days later 1.25 inches of rain fell. The result of this excess of moisture—3.25 inches in 1 week—was that the entire crop was over-sized for crating and had to be marketed in baskets as jumbo melons at a reduced price. Thirty-five percent of cracked melons were graded out. On corresponding unirrigated plots, only 24 percent of the melons were cracked.

As a rule, the first irrigation should be made when melons begin to set, early in July, and two or three additional applications should follow at intervals of a week to 10 days.

Dry weather at maturity is conducive to high quality. On the other hand, drouth and high temperatures during the "sizing up" period result in small, prematurely ripened fruits of poor flavor.

On Aug. 1, 1925, a count was made by Mr. L. B. Hoopes to determine the influence of irrigation upon the maturity of fruit of the variety, Defender. All melons which had reached complete development as to size and netting were included in the count. The average count of mature melons from seven 100-foot rows of the irrigated plot was 63 melons per row. The average on the same basis from the check plot was 41 melons. Such a gain (54 percent) in early melons is important from the standpoint of market returns because the price often falls rapidly as the supply of home-grown melons increases on the market.

Sweet Potatoes

The ability of the plant to utilize soil moisture is influenced by the character and extent of the root system. Studies of the root development of the sweet potato made by Weaver and Bruner[9] showed that 3 weeks after planting the roots were abundant and extended obliquely downward 17 inches. Seven weeks after transplanting the roots had extended to a working depth of 2.6 feet with a lateral spread of from 2 to 3 feet.

Similar studies made on the Buckner sands at Muscatine indicate that these figures are conservative. At Muscatine it was found that roots of the more vigorous varieties often interlap in the middle of rows spaced 3 feet 10 inches apart and penetrate to a depth of from 4 to 5 feet. The average working depth of the roots, according to Weaver and Bruner[10], is about

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[9] Weaver, John E., and Bruner, William E. Root development of vegetable crops. p. 231. McGraw-Hill Book Co., New York. 1927.

[10] Ibid., p. 235.

TABLE 12. YIELD OF SWEET POTATOES—PROLIFIC.

	1925		1927		1928	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total yield	139	108.6	160	163	119	123
Bushels No. 1	117.3	78.2	106	99	75	45
Bushels No. 2	21.7	30.4	54	64	44	78

	1929		1930		1931	
	Irrig.	Check	Irrig.	Check	Irrig.	Check
Total yield	143	138	136.1	42.0	111.7	22.8
Bushels No. 1	112	110	118.2	26.6	84.0	None
Bushels No. 2	31	28	17.9	15.4	27.7	22.8

	6-year average		Av. percentage of increase
Total yield	134.8	99.6	35.3
Bushels No. 1	102.1	69.6	46.7
Bushels No. 2	32.7	39.7	—17.6

2½ feet. The deep rooting habit may be a factor in the ability of the plant to endure drouths better than most vegetables; in fact, the sweet potato appears more tolerant to drouth than to a waterlogged soil.

The sweet potato possesses an extensive leaf system and consequently the loss of moisture from transpiration is large. Numerous counts made by the senior author indicate that 12 lateral branches per plant is rather common, with an increasing number on the heavier soils. On the basis of 14 lineal feet per vine, which was the estimated average, a single plant possesses 168 lineal feet of vine. Planimeter readings on 100 sweet potato leaves of the variety, Prolific, gave an average of 6.8 square inches per leaf. Five hundred leaves per plant were found to be a common number for this variety. The leaf area of a single plant is probably not far from 25 square feet, an evaporating surface which requires large amounts of water.

The variety, Prolific, a type of the Big Stem Jersey, was used throughout the experiment. This variety was selected because it is the leading commercial variety in this region. The plants were set in ridges from 6 to 7 inches high, the rows being 3 feet 10 inches apart and the plants 14 inches apart in the row. The plants were set about the middle of May and the crop was dug early in October.

The average total yield for the 6 years for the irrigated plots was 134.8 bushels per acre against 99.6 for the check. The significant factor, however, was the yield of merchantable or No. 1 stock rather than the total yield. These figures were: 102.1 bushels against 69.6, or a difference of 47 percent in favor of irrigation. In 2 of the 6 years, irrigation did not show great increases in yield. In the other 4 years the differences were important, and in one of them (1931) irrigation meant the difference between a moderate crop and a total failure.

The year 1930 was marked by high temperatures and low rainfall. The irrigated plot yielded 118.2 bushels of No. 1 as compared with 26.6 for the check.

In general the returns from irrigation of sweet potatoes for the period of the study showed a wide variation. The returns in 4 of the 6 years of the experiment emphasized the risk the grower takes who does not possess irrigation equipment. On the other hand, the returns from the irrigation of sweet potatoes are not so large as those from some of the other vegetables because of the drouth resistant qualities of this plant and its ability to recover if rain becomes available later in the season.

When the development of the crop is delayed because of moisture deficiency, the danger of frost becomes serious. This phase of the problem is touched on in the following field notes of Mr. L. B. Hoopes, who was in charge of the experimental plots in 1925:

"For digging in early August, irrigation was absolutely necessary. The farmers who did not irrigate secured a good yield (later in the season) due to heavy rains in September and early October, but the development of the tubers was delayed and this, in turn, delayed digging until early October. Many of these growers lost heavily in the freezes of Oct. 7 and 15; in fact, some fields were never dug at all."

Furrow irrigation presupposes the lateral movement of moisture through the soil from the furrow to the ridges. The major portion of the root of the sweet potato is under the ridge. It is also here that the fertilizer has been placed; and its utilization is dependent upon an adequate moisture supply to bring it into solution. Numerous examinations of the soil directly under the hill were made following irrigation to determine the amount of moisture that reached the ridge area. The lateral movement of water through the soil was found to be very slow. Even a complete soakage of the furrows did not wet the soil under the hills to the degree anticipated.

Shull[11] has pointed out that the main movement of water in the soil is downward (in response to gravitation) and that the

[11] Shull, C. A. Absorption of water by plants and the forces involved. Jour. Amer. Soc. Agron., 22: 467. 1930.

capillary movement of moisture in the soil is not the important factor it was formerly considered to be.

It therefore seems probable that a greater utilization of irrigation water would be obtained if the water were dammed in the furrow until it floods over the ridges. This would make possible the soaking of the ridge areas. This plan involves considerably greater time and labor in the irrigation of sweet potatoes, but would probably give correspondingly greater returns. In this connection the plan of using rather flat, low ridges offers advantages. The practice of setting sweet potato plants on ridges was developed for drainage purposes, as the sweet potato roots are intolerant to the poor aeration resulting from wet soil. In the case of the Buckner sands, which are underlaid with gravel, a moisture deficiency rather than an excess is likely to be a limiting factor. Ridging tends, on the one hand, to increase evaporation and, on the other, to hinder thorough irrigation. On the type of soil used in this experiment, a shallow ridge would seem to have advantages.

Some growers make a practice of turning the vines back over the ridges in order to hasten the flow of water. In this manner the work is expedited but at the expense of a thorough job of watering. The presence of the vines tends to hold back the water and thus gives it a chance to penetrate the soil.

PAPER AND STRAW MULCHES

The use of paper and straw mulches to conserve the soil moisture from spring rains and to tide plants over drouth periods has been suggested as an alternative to irrigation. Straw and paper-mulched plots were laid out in conjunction with the tomato plots of the irrigation experiments. The results are presented herewith.

Results With Straw Mulch at Ames

The straw mulch, approximately 6 inches deep after it had settled, resulted in marked increases in yield of tomatoes over

TABLE 13. YIELD OF TOMATOES IN POUNDS PER PLANT FROM PAPER AND STRAW MULCH PLOTS.

	1926	1927	1928	1929	1930	Average percentage gain
Check	17.5	13.6	25.7	33.5	21.8	
Straw	25.0	22.2	30.0	48.4	21.0	30.8
Paper				43.3	27.8	28.6

the check plots in 4 out of 5 seasons. The average yield per plant was 22.4 pounds on the check plots and 29.3 pounds on the straw-mulched plots. In 1930, although it was a dry year, mulching did not increase the yields. It was a year of high temperatures, a factor not alleviated by supplementing the moisture supply. In July the maximum temperature was above 90° F. for 22 days and above 100° F. for 9 of these days. The temperatures for the first 10 days of August were too high for optimum growth. The "blossom drop" was also heavy, resulting in a light set of fruit.

Results With Paper Mulch at Ames

The soil temperature under the paper mulch averaged 5 degrees higher than that in the check plots. A higher percentage of the total yield was harvested before Aug. 1 from the paper and straw-mulched plots than from the checks. Since prices are usually higher in the earlier part of the season, this tendency toward early maturity is a distinct advantage.

The high original cost of mulch paper (estimated at $50 to $60 per acre in 1929), coupled with the fact that it lasts but a single season, stands in the way of its use by the commercial grower. In localities where straw is abundant its use as a mulch for tomatoes may prove advantageous, especially in dry seasons. To eliminate the seed, straw should be reforked before it is applied as a mulch.

Results With Paper Mulch at Muscatine in 1930

The first heavy picking of Earliana tomatoes was obtained from both the paper-mulched and check plots on Aug. 1. The yield from the check plot was 28 percent greater than from the paper-mulched plot. For the next two harvests the differences were even greater in favor of the check plots. This result was no doubt due to the high temperatures under the paper mulch. An attempt was made to determine the difference in temperature between the check and mulched plots by means of a soil thermograph, but, in the case of the paper-mulched plot, the thermographic charts did not run sufficiently high to record the temperatures. It was estimated that the maximum soil temperature under the mulch was 10 degrees higher than that of the check plot.

The total yield for the check plot was 302 pounds and the yield from the paper-mulched plot was 183 pounds. From the standpoint of both yield and early maturity, the results with paper mulch were disappointng. Mr. L. B. Hoopes, who was in immediate charge of the plots, noted that the "fruits from the paper mulch rows were uniformly smaller and showed more scalding."

The results with Defender muskmelons on the Muscatine plots indicated a gain in earliness of maturity from the use of mulch paper. The first important picking was made on Aug.

27. The check plot yielded 153 prime melons and the paper plot 202, a gain of 32 percent. The record for the entire season, however, was as follows: Check Plot, 324 prime melons; paper-mulched plot, 327. The gains from the paper mulch, as regards either earliness or total yield, were not sufficient to justify the cost of the mulch on the basis of one year's results.

APPENDIX

CLIMATOLOGICAL DATA—DES MOINES STATION

Table 14 contains a summary of drouth periods experienced in central Iowa in the period from 1881 to 1930.

TABLE 14. PRINCIPAL DROUTHS AT DES MOINES, IOWA.
(June, July, August)

Year	Drouth period			Precipitation—inches		
	Began	Ended	Days	Total during drouth period	Deficiency	Total during preceding 30 days
1881	July 18	Aug. 12	26	.14	2.69	12.84
1886	June 28	Aug. 11	45	.44	4.57	1.51
1889	July 24	Aug. 8	16	Trace	1.62	4.46
1893	Aug. 25	Sept. 28	35	.20	3.89	2.18
1894	July 4	Aug. 10	38	.28	3.98	1.68
1901	July 4	July 28	25	.10	2.75	3.24
1911	May 31	June 16	17	.15	2.72	2.43
1911	Aug. 19	Sept. 5	18	.04	1.71	2.31
1913	July 12	Aug. 9	29	.16	3.01	3.99
1916	July 20	Aug. 11	23	.10	2.31	2.04
1918	July 16	Aug. 14	30	.29	3.16	2.74
1919	June 21	July 10	21	.22	2.44	7.52
1920	July 22	Aug. 5	15	Trace	1.51	6.23
1925	July 15	Aug. 1	18	.03	2.01	4.89
1927	June 12	July 23	42	.43	5.11	3.24
1929	June 8	June 25	18	.13	2.84	3.27
1929	July 15	Aug. 4	21	.19	2.17	4.48
1930	July 5	Aug. 4	31	.33	3.17	3.01

The worst drouth on record in Iowa occurred in 1886. The annual report of the Iowa Weather Service[12] for that year contains the following:

"The rainfall has been absolutely zero at a number of stations and a mere trifle at a number of others. The Missouri slope and northeastern Iowa have received a moderate rainfall, but nearly all other parts of the state had less than ½ inch the entire month of July . . . At the central station (Iowa City) the total rainfall of the month was only 1/10 of an inch, amounting to only 2 percent of the normal value."

Reed[13] reports the significant fact that an appreciable amount of rainfall has been transferred from summer to fall, the amount of the shift being upward of 15 percent. Such a trend would indicate an increasing demand for summer irrigation.

Reed also notes that a study of the secular trend of Iowa precipitation shows a decrement which, taken for the state as a whole, indicates a decrease of 0.036 inches per year or a total of 1.9 inches for the 53-year period of 1875-1927. The dry trend for the summer months by sections is indicated on the accompanying map (fig. 3).

The moisture supply in the subsoil at the beginning of a drouth is an important factor. In 1881, for example, the precipitation for the 30 days preceding the drouth was 12.84 inches, or over one-third the normal supply for an entire year. Obviously much of this dis-

[12] Ann. Rpt. Iowa Weather Service, Iowa State Board of Agr. 1886.
[13] Reed, Chas. D. Secular trend in Iowa precipitation. Monthly Weather Rev., U. S. Dept. Agr., vol. 58. April, 1930.

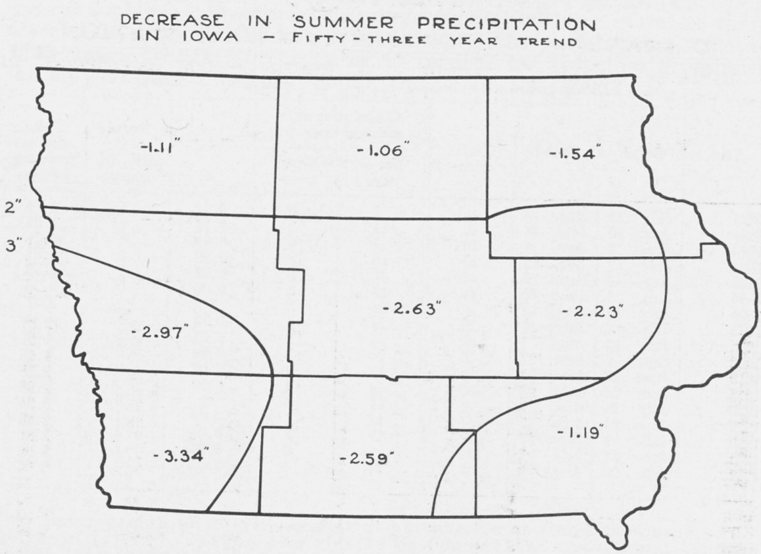

Fig. 5. The figures shown in the various sections of the above map show the decrease (in inches) of summer rainfall during a 53-year period.

appeared as "run off" rather than serving as a supply for the dry period which followed.

Reed[14] also presents certain conclusions regarding weather abnormalities which are of value to the grower as an indication of the probable weather forecast. His deductions are based upon the principle of "The greater the abnormality, the more certain the sequence."

"When June temperature was 4 degrees or more below normal, July was wetter than normal in 80 percent of such instances. Conversely, when June temperature was 3 degrees or more above normal, July was drier than normal in all of the five cases of record." Mr. Reed concludes that when June temperatures average 3 to 4 degrees above normal, July precipitation will average below normal nearly 100 percent of the time over much of the Mississippi Valley.

"When June precipitation has been 2 inches below normal, July precipitation has been below normal in four out of five cases or 80 percent. When July rainfall was 2 inches below normal or July temperature 3 degrees above normal, August precipitation was below normal in five out of six cases or 83 percent. There is a well defined tendency for abnormal July weather to extend into August in Iowa . . .

"When the abnormality has an accumulated departure extending over a 30-day period, it is easy to predict another 30-day period of restoration, the average of which will have the same sign of departure as the first month, when temperature is compared with temperature or precipitation with precipitation; but when temperature is compared or correlated with precipitation, the sign of departure is opposite; that is, the correlation coefficient is negative."

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[14] Reed, Charles D. Iowa Crop and Weather Service. Before Amer. Meteorological Society. Dec. 28-30, 1931. Unpublished.